CONVENTIONAL DENSITY TESTING

August 16, 2002
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North Carolina Department of Transportation
Materials and Tests Unit – Soils Laboratory

SECTION 1 – INTRODUCTION TO DENSITY CONCEPTS

Definition of Density

Soil consists of three components: solid particles, air, and water. In engineering applications involving soils, air and water are collectively referred to as voids. In a given amount of soil, the solid particles and the voids occupy a certain amount of space, or volume. Therefore, the volume of a soil mass is the sum of the volume of the solids and the volume of the voids.

The term density has varied meanings in different fields of sciences. For our specific field of study (i.e., the engineering aspect of soils), we will use weight density, which is defined as weight per unit volume (in English units, weight density can have units of pounds per cubic foot). For brevity, the term "density" will refer to weight density unless otherwise specified. Mathematically, the density of soil is obtained as follows:

$$\text{Density} = (W_s + W_a + W_w) / (V_s + V_a + V_w)$$

where

W_s = weight of solids
W_a = weight of air
W_w = weight of water
V_s = volume of solids
V_a = volume of air
V_w = volume of water

Three Phases of Soil

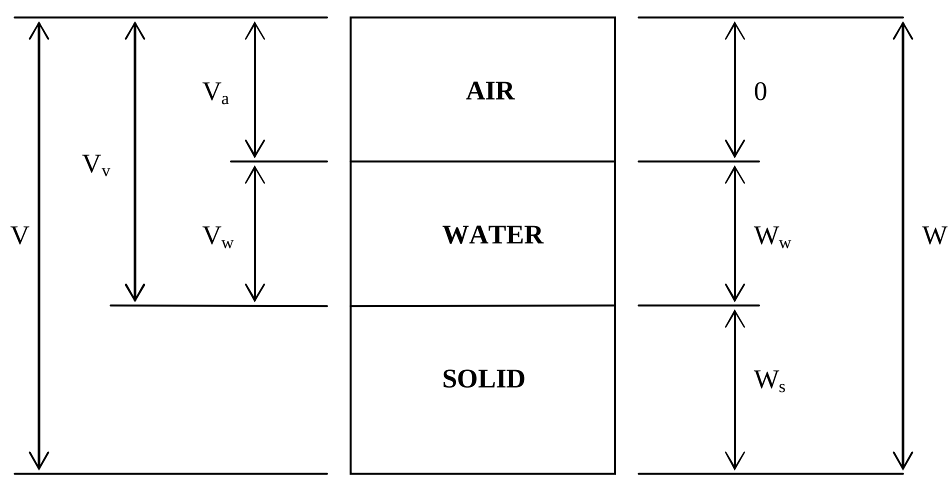


Diagram 1

The weight of air is negligible compared to the weight of water and solids, and for all practical purposes, can be ignored. The volume it occupies, however, is significant. Therefore, for soils engineering purposes, the following mathematical definition of density is acceptable and generally used:

$$\text{Density} = (W_s + W_w) / (V_s + V_a + V_w)$$

It can be noted that water can be present or absent (a completely dry soil). For engineering purposes, a distinction is made between the two values of density with and without water present. Wet density is the density of the soil mass, including the moisture (or water) contained in the void spaces. Dry density is the density of the soil mass without the moisture.

When water is present, the quantity of water relative to the quantity of solids is defined mathematically as its moisture content. Moisture content can be expressed as follows:

$$\text{Moisture content} = W_w / W_s$$

The dry density of a soil mass is what affects its important engineering properties, such as strength, permeability, and compressibility. From an engineering standpoint, we would like to increase the strength, and decrease permeability and compressibility of a soil mass, and these are achieved by increasing dry density.

Definition of Compaction and Optimum Moisture

Compaction is the process by which a soil mass is subjected to compressive forces (in the form of static weights, vibration, blows from heavy objects, or a combination of some or all of these) for the purpose of decreasing the volume of voids, thereby increasing the dry density. Decreasing the volume of voids would mean decreasing the volume occupied by air and water. Water is incompressible, meaning the volume occupied by a given quantity of water cannot be reduced further. However, air is compressible, and in applying compactive effort to a soil mass, it is air whose volume is reduced.

It is an established fact that the amount of water in the soil mass affects how well the air in the same soil mass is squeezed out or compressed. Water acts as a lubricant that allows soil particles to be rearranged during the compaction process. Too little water means too little "lubrication" of the soil particles. However, too much water is also a hindrance to squeezing out or compressing the air, because the water will tend to absorb the energy from the compactive forces. Between having too much and having too little water, there is a quantity of water that will allow the compactive forces to result in the maximum possible dry density. This quantity of water is expressed in terms of the moisture content and is referred to as the soil's optimum moisture content.

For a particular soil, the optimum moisture is defined as the moisture content at which a soil can be compacted to its maximum dry density with a given compactive effort.

Standardized Tests for Determining Maximum Dry Density

In the definition of optimum moisture, it should be noted that the maximum dry density obtained is for a specific compactive effort. Standardized tests for determining maximum dry density involves varying the moisture content of a soil mass, subjecting the soil mass to a specific compactive effort (which remains the same for the test), and keeping track of the resulting values of dry density. The result is a correlation between moisture content and dry density, which can be plotted. The maximum dry density can then be obtained.

Examples of standardized tests that will be used for our purposes are **AASHTO T-99** and **AASHTO T-180**. These tests (with some NCDOT modifications) are used to establish the maximum dry density of a given soil mass.

SECTION 2 – DENSITY SPECIFICATIONS

Inspection of Earthwork, Subgrade and Bases on a Construction Project

When inspecting a construction project a Technician must understand the plans, specifications, and any project special provisions. The **NCDOT Construction Manual** can provide guidance when inspecting soils related items on a project, a Technician should become familiar with Divisions listed in the following table:

Classification	Reference Division
Earthwork	Division 2
Subgrade and Bases	Division 5

Table 1 Related Reference Divisions for NCDOT Construction Manual

The Goal of Field Density Tests

Field density tests are conducted to determine if the material being compacted has attained a minimum acceptable value of dry density. This minimum acceptable value is expressed as a percentage of the maximum dry density as determined by a standardized test in which the material is subjected to a predetermined compaction effort. For example, if the test to determine maximum dry density is AASTHO T-99, the density requirement can be expressed as follows:

"The material shall be compacted to at least 95% of the maximum dry density as determined by AASHTO T-99 as modified by the Department."

In the above example, the quantity represented by 95% is what is referred to as percent compaction. Mathematically, percent compaction is the ratio of the in-place dry density of the compacted soil ($\gamma_{in\text{-}place}$) to the maximum dry density as determined by standardized tests (γ_{max}). That is,

$$\text{Percent compaction} = (\gamma_{in\text{-}place}) / (\gamma_{max})$$

The tests discussed in the sections to follow are aimed towards determining $\gamma_{in\text{-}place}$, γ_{max}, or the ratio itself directly.

Classification of Materials

The testing frequency and density requirements of soil depend on its classification in terms of how it is constructed. These classifications and reference section number from the **NCDOT Standard Specifications for Roads and Structures** are listed in the following table (when inspecting a project a Technician should review these sections if soil or aggregate is being utilized in the construction process):

Classification	Reference Section
Embankment	Section 235
Subgrade	Section 500
Aggregate Stabilized Subgrade	Section 510
Chemically-treated Subgrade	Section 501 (lime) Section 542 (cement)
Aggregate Base Course (ABC)	Section 520
Cement-treated Base Course (CTBC)	Section 540

Table 2 Related Reference Section for NCDOT Standard Specifications for Roads and Structures

In general, embankment refers to any layer placed below the subgrade. The subgrade is usually 8-inches thick and refers to the portion of the roadbed prepared as a foundation for the pavement structure (including the curb and gutter). Base Course refers to a layer of planned thickness placed immediately below the pavement or surface course.

Testing Frequency Requirements

The frequency with which a compacted material is checked for density (that is, percent compaction) depends on its classification. The Department requires the following testing frequencies:

- Embankments – one test every 5,000 yd^3 (4,000 m^3) or fraction thereof. Since problems can develop as an embankment is being constructed a Technician, should not wait until several layers have been placed to perform a density test. Therefore, the Department recommends the Technician should perform a density test on every other lift of an embankment as it is being constructed. NOTE: If an embankment contains rock the Technician should attempt to perform a density test using the methods described in Section 3 of this manual (Test 1-A, 1, or 2). However, if an area cannot be tested successfully, a note is made on the density report (M&T Form 504) that states "Too rocky to run". Exempt (do not perform) density tests from rock embankments (constructed with larger rock boulders or broken pavement) or "rock-lifts", which cannot be tested by approved methods. If a rock-lift is being placed indicate by placing a note on the density report (M&T Form 504) "Rock-lift".
- Subgrade – one test every 1,000 linear feet for roads up to 28 feet (8.5 meter) in width; for roads greater than 28 feet in width, one test every 3,000 yd^2 (2,500 m^2).
- Chemically Treated Subgrade (Lime or Cement) – Refer to page 7
- ABC and CTBC – same as subgrade except when there are separate shoulders, in which case take one test every 2,000 linear feet (600 meters).

Density Requirements

The Department has the following density requirements for the various materials:

- Embankment - compacted to at least 95% of the maximum dry density as determined by AASHTO T-99 as modified by the Department.
- Subgrade - compacted to at least 100% of the maximum dry density as determined by AASHTO T-99 as modified by the Department.
- Chemically treated subgrade (lime or cement) - compacted to at least 97% of the maximum dry density as determined by AASHTO T-99 as modified by the Department.
- Aggregate-stabilized subgrade - compacted to at least 100% of the maximum dry density as determined by AASHTO T-99 as modified by the Department.
- Aggregate Base Course (ABC) - compacted to at least 100% of the maximum dry density as determined by AASHTO T-180 as modified by the Department.
- Cement-treated Base Course (CTBC) - compacted to at least 97% of the maximum dry density as determined by AASHTO T-180 as modified by the Department.

Chemical Stabilization

When designing a road, the Engineer must consider vehicle loads supported by the pavement structure. Obviously these loads are transferred through the pavement structure into the supporting soils. Due to the various types of soils in North Carolina, the Engineer may decide that it is economically necessary to chemically stabilize the subgrade in order to provide the required strength for supporting the roadway. Depending on the type of soil, lime or cement is generally added to stabilize a subgrade.

When adding cement or lime, moisture control is critical to ensure proper hydration. Without proper hydration the chemically stabilized section may not achieve the required design strength and possibly lead to structural failure. Materials and Tests and Geotechnical Engineering Units recommend the following procedures for monitoring chemically stabilized sections for density acceptance and proper moisture control. The procedures and equipment required for monitoring soil densities are similar to those for un-stabilized soils, with the following additions:

1. The Geotechnical Engineering Unit of the Department can provide assistance in the stabilization operation, and should be consulted prior to beginning the operation.
2. A moisture-density curve must be established at the beginning of the first day of operation. The sample for performing the curve must be taken <u>after the cement or lime has been mixed in the soil</u> but <u>before water is added</u>. A new moisture-density curve is to be established when a significant change in the soil occurs or upon recommendation by the Engineer. The moisture-density curve should be made available to the Geotechnical Engineer in the field to verify if any adjustment in the moisture content is needed. Once the Contractor is ready for a

density test in the stabilized section, perform a Test 1 (long test) in the area where the sample was obtained for the moisture-density curve. As required with all conventional density testing, 1 out of every 15 tests must be a Test 1 (long test) with a moisture-density curve.

3. Test 1-A (short test) will be performed as outlined in this manual, with the following addition: a 300-gram in-place moisture content sample must be taken prior to compaction. This moisture sample should represent the moisture content of the area as the contractor began compacting the soil. After compaction, a Test 1-A will be performed at the approximate location where the moisture sample was taken. The moisture content will be documented on the density test report for the Test 1-A.
4. The frequency for density acceptance testing will be based on the number of operation(s). An operation is defined as one tanker load. One density test will be required for each operation for the first 4 operations of a day's production. Once the day's production surpasses 4 operations but is less than 8 operations, one density test per 2 operations will be required. Once the day's production surpasses 9 operations, one density test per 3 operations will be required.

    For example:

    The Contractor begins the first chemical stabilization operation at 6:30 a.m. and completes the fourth operation that same day at 1:00 p.m. Each of the first four operations must have a density acceptance test. The Contractor continues production that same day and completes operations 5 through 8 by 4:30 p.m. The chemically stabilized area completed between 1:00 and 4:30 p.m. (operations 5 – 8) would require a total of two density acceptance tests (one test per two operations). The Contractor continues production that same day and completes operations 9 through 12 by 6:30 p.m. The chemically stabilized area completed between 4:30 and 6:30 p.m. (operations 9 – 12) would require a total of one density acceptance test (one test per three operations).

SECTION 3 – OVERVIEW OF THE FOUR FIELD TESTS

- Density Test 1-A

  In this test, the compaction of embankments and subgrades consisting primarily of soil in which the moisture content of the soil is not determined for each test.

  This test is also known as the "short test" because of the relatively short time required performing this test. This test uses a volumeter with a water-filled balloon to determine both the volume of the soil removed from a roadway test hole and the volume of the same soil after being compacted in a standard compaction mold. The soil is compacted in the mold at optimum moisture, and therefore will yield the maximum dry density. Recall that

  $$\text{Percent compaction} = (\gamma_{\text{in-place}}) / (\gamma_{\text{max}})$$

  In term of the unit weight in the "hole" and the unit weight in the "mold", we have

  $$\text{Percent compaction} = (\gamma_{\text{hole}}) / (\gamma_{\text{mold}})$$

  Since the soil that was taken out of the hole is the same soil compacted in the mold, we can express percent compaction in terms of volume as follows:

  $$\text{Percent compaction} = (V_{\text{mold}}) / (V_{\text{hole}})$$

  Where V_{mold} and V_{hole} are the volume occupied by the soil in the mold and hole, respectively. Because no unit weights are calculated, it is not required to determine the moisture content of the soil.

  Test 1A is intended for use on embankments and subgrades that are predominately soil, that is, with little or no rock or aggregate. When more than 1/3 of the soil (by weight) consists of aggregate larger than approximately ¼ inch in size, performance of the test may be difficult and the accuracy questionable. In this situation, it will be necessary to use Density Test No. 2, which is designed for soil-aggregate mixtures.

- Density Test 1

  In this test, the compaction of embankments and subgrades consisting primarily of soil in which the moisture content of the soil is determined for each test.

  This test is also known as the “long test” because of the longer amount of time (that is, compared to the “short test”) required to perform this test. This test uses a volumeter with a water-filled balloon to determine the volume of soil removed from a roadway test hole. Then the weight of the dry soil removed from the hole is determined by weighing the wet soil and then determining the moisture content. Using the hole volume and the dry unit weight, the in-place dry density ($\gamma_{in\text{-}place}$) can be calculated.

  A separate soil sample is compacted in a standard mold at the optimum moisture. The volume occupied by the wet soil in the mold is determined using the volumeter, and then the moisture content determined. The maximum dry density (γ_{max}) can be calculated. Then, we have

  $$\text{Percent compaction} = (\gamma_{in\text{-}place}) / (\gamma_{max})$$

  Test 1 is intended for use on embankments and subgrades that are predominately soil, that is, with little or no rock or aggregate. When more than 1/3 of the soil (by weight) consists of aggregate larger than approximately ¼ inch in size, performance of the test may be difficult and the accuracy questionable. In this situation, it will be necessary to use Density Test No. 2, which is designed for soil-aggregate mixtures.

- Density Test 2

  In this test, the compaction of embankments and subgrades consisting of a soil-aggregate mixture, (i.e. when more than 1/3 of the soil (by weight) consists of aggregate larger than approximately ¼ inch in size) is determined**.** Soil-aggregate mixtures may be soils naturally containing aggregate or soils stabilized by mechanically adding and mixing aggregate material.

  Test 2 is similar to Test 1 in the sense that percent compaction is calculated as follows:

  $$\text{Percent compaction} = (\gamma_{in\text{-}place}) / (\gamma_{max})$$

  However, the in-place density of the soil-aggregate mixture is measured using a calibrated steel ring instead of a volumeter. The maximum dry density of soil-aggregate mixtures is determined by AASHTO T-99 Method C or Method D, as modified by the Department. Detailed steps for these procedures are given in Section 7.

- Density Test 3

  Test 3 is used to determine the compaction of Aggregate Base Course (ABC), that consist of a mixture of coarse and fine aggregate, with very little soil.

  Again, as in Test 1 and Test 2, percent compaction is calculated as follows:

  $$\text{Percent compaction} = (\gamma_{\text{in-place}}) / (\gamma_{\text{max}})$$

  The Soils Laboratory will provide the value of the dry AASHTO T-180 density (maximum dry density or Unit Weight). The Unit Weight of the ABC can be obtained on the Materials and Tests website or by calling the Soils Laboratory (919) 329-4150. Only the in-place density of the material will be determined in the field, and this is accomplished using a calibrated steel ring. Details of the procedure for determining the in-place density is given in Section 8 of this manual.

SECTION 4 – DETERMINATION OF OPTIMUM MOISTURE

Standard Moisture-Density Curve – AASHTO T-99

It was previously mentioned that, for a fixed amount of energy applied during the compaction process, there is a correlation between the maximum density to which a soil can be compacted and the moisture content of the soil during compaction (compaction water content).

A standard test has been devised which makes it possible to determine in the laboratory the moisture content that will give maximum density with a given amount of energy. In this test the soil is compacted at a number of different moisture contents (usually in increments of two percent), ranging from dry to wet. The fixed amount of energy according to AASHTO T-99 is applied (25 blows, 12-inch vertical drop using a 5.5-lb hammer), and the dry density and compaction moisture content are determined in each case. The dry densities are plotted against the corresponding compaction moisture contents and a smooth curve is drawn throughout the data points. A minimum of four data points is required for this test. In general, as the moisture content is increased from the dry side, this curve rises to a maximum density and then declines. The highest point on the curve indicates the "maximum dry density" for the soil tested. It is sometimes referred to as the "Standard AASHTO Density". The moisture content corresponding to this maximum density is called the "Optimum Moisture Content".

Equipment Needed

The following equipment is necessary for performing AASHTO T-99.

- 3-inch auger
- Large Spoon
- 50-pound weight
- Graduated cylinder (with graduations in milliliters)
- Soil Pan
- Pie plate (9" x 1 ½")
- Scales
- Frying pan
- Steel straight edge
- Compaction mold (1/30 ft^3.)
- Sample extractor
- Compaction rammer (5 ½ pounds, 12-inch drop)
- Gas burner
- Square shovel

Step-by-step Procedure for Performing AASHTO T-99

1. Level the electronic scale.
2. Verify that the 2,000-gram weight reads as 2,000 grams on the scale, with a +/-1-gram tolerance.
3. Weigh the empty mold and record.
4. Obtain enough soil to fill the soil pan to 2/3 full (when performing this test in conjunction with Test 1, obtain soil from the test hole).
5. Break up and pulverize the soil.
6. Dry or add water to the soil as necessary, and mix for uniform water content. Repeat step 5-6 until water content is judged to be at an appropriate starting point (about 5% dry of optimum).
7. Weigh and set-aside 4,000 grams from the soil in the soil pan. This is the soil that will be used for the test. Discard the rest of the soil in the soil pan.

Steps 8 to 21 will be performed 4 times. Each obtained value of dry density and moisture content will be plotted, resulting in the material's moisture-density curve.

8. Place a first layer in the mold.
9. Apply compactive effort (25 blows, 12-inch drop).
10. Place a second layer in the mold and apply compactive effort.
11. Place a third layer in the mold and apply compactive effort.
12. Scribe around the top (third) layer and then remove the mold collar.
13. The top of the third layer must be ¼ to ½ inches above the top of the mold.
14. Scrape off the excess soil with the straight edge until the surface is flush with the top of the mold. Fill in exposed voids with fine material.
15. Weigh the mold with the soil and record the weight.
16. Extract the soil pill with the sample extractor.
17. Using the straight edge, split the soil pill down the middle lengthwise.
18. Obtain 300 grams of soil from the scrapings. This is the sample for determining the soil's moisture content.
19. Dry the soil. When using a burner, be sure not to overheat the soil.
20. Weigh the dry soil and record.
21. Add 2% water per weight of the soil remaining in the soil pan.
    NOTE: If the test is begun with exactly 4,000 grams of soil and for each "point" a 300-gram moisture sample is removed, the amount of water to be added are as follows: 1st point – none; 2nd point – 80 ml; 3rd point – 75 ml; 4th point – 70 ml. These amounts account for 5 to 10 ml of water lost due to evaporation.
22. Record all data on M&T Form 506, and plot the moisture-density curve.

Using the "Squeeze" Method

The "Squeeze" method is a "short cut" approach for determining the optimum moisture of a soil mass, and can be performed with reasonable accuracy by an experienced technician. This method is <u>not applicable to all</u> types of soils, but works well when the soil has a significant fraction of cohesive particles (i.e., clay or some silts).

Prior to performing this test on a soil mass, all lumps or clods should be pulverized or broken down as recommended by AASHTO Method T-99. The soil mass should be thoroughly mixed until the moisture is uniform. A handful of loose soil is taken in one hand and firmly squeezed into an elongated mass. The squeezing should be fairly firm and yet not with all one's strength (i.e., not a bone crushing grip).
The soil mass is close to or at optimum moisture if the following are true:

1) The soil mass exhibits cohesion - Release the soil from the hand after squeezing. If the soil mass does not break apart, it is an indication that the soil is at or above "optimum". If the soil mass breaks apart upon releasing the pressure applied, then a small amount of water should be added and thoroughly mixed with the soil until the elongated soil mass will remains intact after release.

2) The soil mass exhibits cohesion under stress - The elongated mass of soil is tossed 3 or 4 inches into the air using the open palm of one hand. This is repeated two or three times. If the soil mass does not break apart, it is an indication that the soil is at or above "optimum". If the soil mass breaks apart as it is tossed, then a small amount of water should be added and thoroughly mixed with the soil until the elongated soil mass will remain during tossing.

3) There is "coolness of the palm" - When the soil mass is wet or moist enough to stick together, note a sensation on your palm. If the soil is at optimum, you should be able to feel a coolness on your palm as the film of moisture evaporates.

Note that the above observations are true even if the moisture content of the soil mass is above optimum. If it is above optimum, the following additional observation can be made: A very noticeable film of moisture will appear on the hand, and part of the soil grains (excluding clay and silt particles) will adhere to the hand. In this case, the soil is above optimum moisture, and it must be dried back slowly until "optimum" is reached. This will be done by air drying or very low heat (140°F maximum).

Using the "Penny Print" Method

After determining the optimum moisture as outlined above, it can be checked by observing the print and depth of the rammer in the soil while compacting it in the AASHTO mold. When the first layer of soil is placed in the mold and after the 24th blow of the rammer has been struck, place the 25th blow in the center of the mold. Be sure before making the 25th blow that the face of the rammer is free from clinging soil particles and held in as nearly vertical position as possible before being dropped. Observe the print of the rammer in the compacted layer. If the soil is at optimum moisture, a full print of the rammer will be observed and the depth of penetration should be about 1/16 inch in depth (approximately the thickness of a penny). If a full print of the rammer cannot be observed, the soil is too dry. If the rammer penetration exceeds 1/16 inch, the soil is too moist.

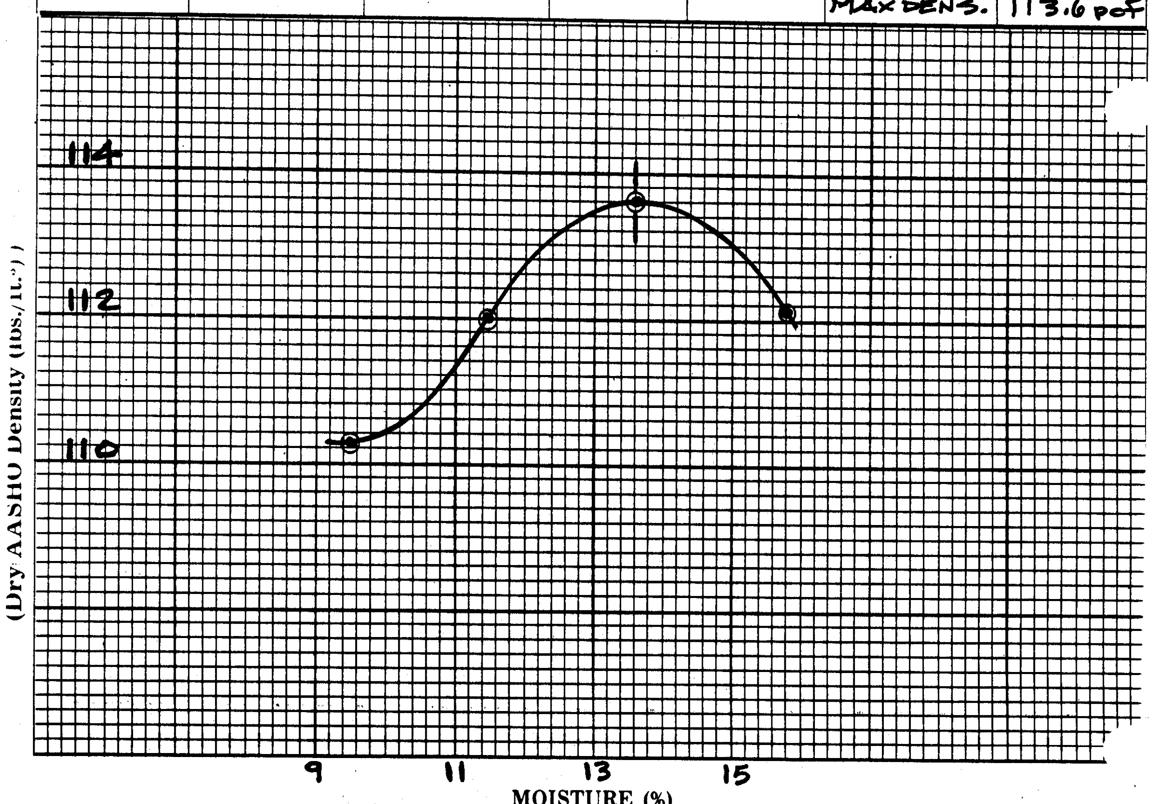
NORTH CAROLINA DEPARTMENT OF TRANSPORTATION
DIVISION OF HIGHWAYS

M & T FORM 506
4-1-76

MOISTURE DENSITY DETERMINATION

Project 8.123456E
Date 4-30-02
County WAKE
Mold 1/30 CU FT
Station 11+91 NBL
Test AASHTO T-99
Sample No. CURVE #1 W/SUBG 2
Submitted By TB GOOD (12345)

Test Number	Wet Wt. (Grams)	Wet Wt. (Lbs./Cu. Ft.)	Wt. Wet Sample	Wt. Dry Sample	Moisture (%)	Dry Wt. (Lbs./Cu. Ft.)
1	1827	120.8	300	274	9.5	110.3
2	1888	124.9	300	269	11.5	112.0
3	1950	129.0	300	264	13.6	113.6
4	1963	129.8	300	259	15.8	112.1
					OPT. MOIST.	13.6%
					MAX DENS.	113.6 PCF



3668 − 1841 = 1827
3729 − 1841 = 1888
3791 − 1841 = 1950
3804 − 1841 = 1963

Figure 1 Example of Moisture-Density Curve AASHTO T-99 (English units)

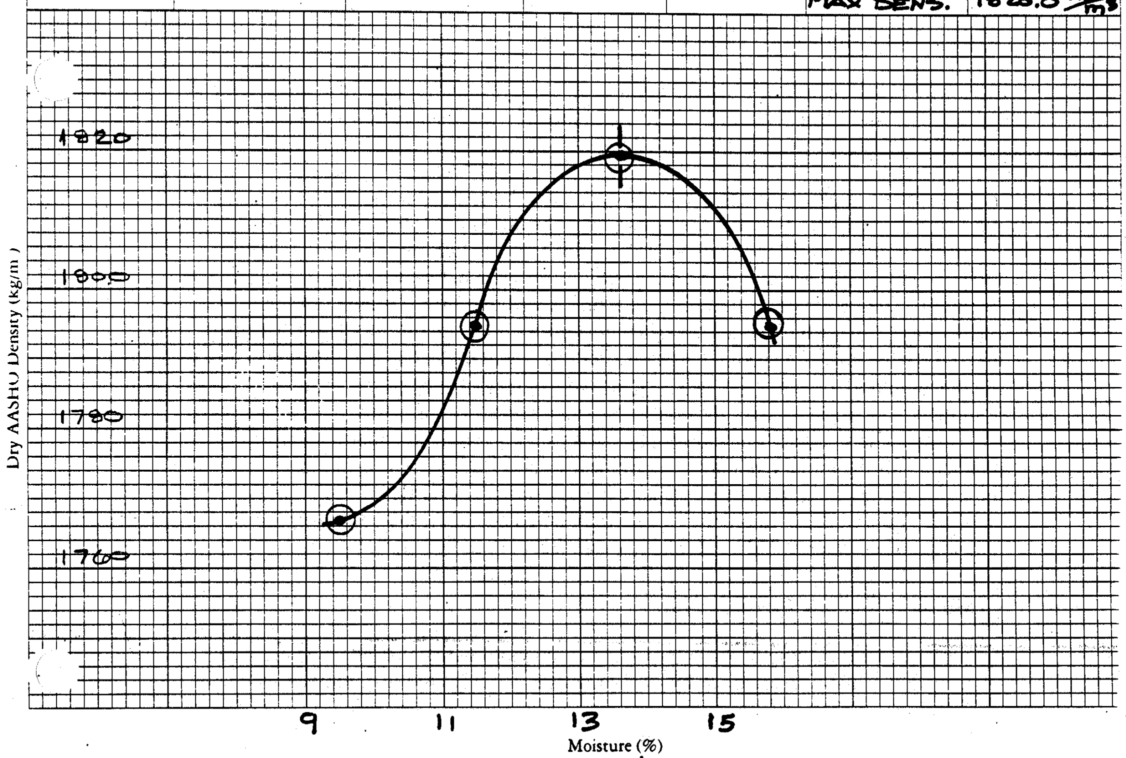
NORTH CAROLINA DEPARTMENT OF TRANSPORTATION
DIVISION OF HIGHWAYS

M & T FORM 506m
Rev. 11/94

MOISTURE DENSITY DETERMINATION

Project: 8,1234567 — Date: 4-30-02
County: WAKE — Mold: 0.000944 m^3
Station: 3+252 — Test: AASHTO T-99
Sample No.: CURVE #2 W/SUBG 27 — Submitted By: [illegible] GOOD (12345)

Test Number	Wet Wt. (Grams)	Wet Density (kg/m³)	Wt. Wet Sample	Wt. Dry Sample	Moisture (%)	Dry Density (kg/m³)
1	1,827	1935.2	300	274	9.5	1767.0
2	1,888	2000.9	300	269	11.5	1794.2
3	1,950	2066.6	300	264	13.6	1819.9
4	1,963	2079.4	300	259	15.8	1795.8
					OPT MOIST.	13.6 %
					MAX DENS.	1820.0 kg/m3



3668 − 1841 = 1827
3729 − 1841 = 1888
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Figure 2 Example of Moisture-Density Curve AASHTO T-99 (metric units)

SECTION 5 – DENSITY TEST 1-A

Also referred to as the “short test”, Test 1-A does not require weighing and drying steps, thereby reducing the possibility of error.

Equipment Needed

The following equipment is necessary for performing of Density Test 1-A.

- Volumeter
- 3-inch auger
- Large spoon
- 50-pound weight
- 50-pound saddle weight for volumeter
- Soil pan
- Steel Straight edge
- Small Spatula
- Compaction mold (1/30 cubic foot)
- Sample extractor
- Compaction rammer (5 ½ pounds, 12-inch drop)
- Square tip shovel
- Water Container (i.e. small squirt bottle or graduated cylinder)
- Water

Determining the In-place Volume

All loose soil is removed from the surface of the layer and an area of about 15-inches square is brought to a smooth flat and approximately level surface by scraping with the steel straight edge, shovel or other suitable instrument.

The volumeter is placed on the smoothed surface of the soil and its position carefully marked by tracing the outside edge of its base. The 50-pound saddle weight is placed on top of the volumeter. Pressure of 4-psi is applied to the volumeter, a reading taken and recorded (this is the actual reading on the volumeter scale before the soil is removed from the hole). The volumeter is removed and a hole about four inches in diameter and six inches deep is made in the middle of the circle inscribing the volumeter base. The soil taken from the hole is placed in a pan for later placement in the compaction mold. It is, of course, important that all of the soil removed from the hole be placed in the pan. The volumeter is then placed over the hole at the exact same location where the initial reading was taken. The saddle, 50-pound weight and 4-psi air pressure are applied in the same manner as for the initial reading to determine a second reading. The difference between the two readings is the volume of the hole in cubic feet. This is also the “in-place volume” of the sample. In order to obtain the desired accuracy, the volume of the test hole must be between 0.0320 and 0.0350 cubic feet.

Determining the "Compacted Volume"

An initial volume reading of the empty compaction mold with collar attached is determined by averaging three readings of the volumeter using the procedures mentioned earlier. This initial volume reading will remain the same as long as the same volumeter and mold are used and the water level in the volumeter remains the same. If any of these are changed, a new initial volume reading must be taken.

The soil taken earlier from the roadway test hole is needed to obtain the "compacted volume" of the soil in the compaction mold. This soil shall be broken up to the extent that the largest clod (not aggregate) should not exceed ¼-inch in size as determined by visual inspection. Any aggregate present in the sample shall be mixed uniformly with the soil and not thrown out. The optimum moisture of the soil is then estimated using the "squeeze" technique. If the soil appears too wet, it must be dried to approximately optimum moisture. If too dry, water must be mixed with it uniformly until approximate optimum moisture is reached. (See Section 4 - Determination of Optimum Moisture). The prepared soil is divided into approximately three equal parts and compacted in the mold. The compaction is done with the 5-½ pound rammer. Twenty-five (25) drops of the rammer from a 12-inch height are applied to each of the three layers. The mold shall be placed on the 50-pound weight or on pavement or similar rigid base while compacting. After all three layers of the soil have been compacted, a second volumeter reading is taken of the compaction mold with the collar still attached. The difference between this reading and the reading of the empty mold and collar taken earlier is the "compacted volume" of the soil in cubic feet. The percentage compaction is simply calculated by this formula:

$$\text{Percent Compaction} = \frac{\text{Compacted Volume} \times 100}{\text{In-place Volume}}$$

Or, as earlier expressed in terms of the "hole" and the "mold",

$$\text{Percent compaction} = (V_{mold}) / (V_{hole})$$

Step-by-step Procedure for Performing Test 1-A

NOTE: All volumeter readings require 4-psi water pressure; use M&T Form 504 to record your results.

1. Take empty mold and collar reading, applying 4-psi to the volumeter water balloon.
2. Prepare a test site by smoothing the surface.
3. Level the plate on the test site.
4. Scribe around the edges of the plate, marking the volumeter valve location.
5. Take the first (or "flat") reading.
6. Dig the test hole, starting off with a spoon and continuing with an auger. Soil should be collected on the soil pan
7. When hole is finished, remove loose soil particles from the hole and the plate and include them with the soil collected in step 6.

8. Check for sharp edges in the hole. If there are sharp edges, move to another location and repeat steps 1-8.
9. Take a second reading with the volumeter, positioning the valve at the marked location. The difference is the volume of the hole occupied by the removed soil.
10. If the difference between the second and the first reading is such that the volume of the hole is less than 0.03200 ft^3, the hole is too small. Remove additional soil and repeat steps 8-10.
11. If the difference between the second and the first reading is such that the volume of the hole is greater than 0.03500 ft^3, the hole is too large. Move to a different location and start over.
12. Clean off excess soil from the auger and spoon, and include them with the soil in the soil pan.
13. Mix the soil until it has uniform water content.
14. Check for optimum moisture using the “squeeze” method.
15. Dry or add water to the soil as necessary, and mix for uniform water content. Repeat step 14-15 until optimum water content is obtained.
16. Move the soil to one side of the pan and divide into three equal layers.
17. Place the first layer in the mold, taking care not to lose any material (place the mold in the soil pan).
18. Apply compactive effort; apply the 25^{th} blow in the center and check for the “penny print.”
19. Place the second layer in the mold, including any rocks that were removed from the hole. Apply compactive effort.
20. After compacting the second layer, place all the remaining soil in the mold and apply compactive effort. On the 18^{th} blow, scrape any soil sticking to the rammer and from the inside wall of the mold above the soil layer.
21. Take a second reading on the mold using the volumeter.
22. The difference between the reading taken in step 5 and step 21 is the volume occupied by the soil in the mold.
23. Percent compaction = (volume obtained in step 22) / (volume obtained in step 9)

<u>Sources of Error for Test 1-A</u>

1. Density hole too small or too big for accurate results.
2. Failure to keep volumeter in good working condition.
3. Operator not understanding the significance of <u>Optimum Moisture</u> and <u>Maximum Density</u>
4. <u>Failure to remove all loose material in hole.</u>
5. Dropping rammer more than 12 inches.
6. Applying more or less than 25 blows to layer of soil.
7. Test performed on “crust” of layer.
8. Spilling soil removed from hole. All soil <u>MUST</u> be compacted in mold.
9. <u>Do Not</u> divide in-place volume by compacted volume.
   NOTE: Correct method is as follows:

$$\text{Percent Compaction} = \frac{\text{Compacted Volume}}{\text{In-Place Volume}} \quad x \quad 100$$

TEST 1A ENGLISH

NORTH CAROLINA DEPARTMENT OF TRANSPORTATION — M & T FORM 504 10-1-80

DIVISION OF HIGHWAYS

FIELD AND A.A.S.H.T.O. DENSITY DETERMINATIONS

Date: 4-29-02

Project: 8.123456E   County: WAKE   Test No. 1

Test Location & Type: 9+22 NBL (Sta; Lane;)   RDWY (Rdwy. or Shldr.;)   SUBG. (Embank., Subg., or Base.)

3' RT (Dist. from C/L; Rt. or Lt.)   -0- (Dist. below Subg. Elev.)

ROAD DENSITY DETERMINATION

Volume of Hole: 2nd Reading .04463
1st Reading .01263
Difference .03200 cu. ft.

VOLUMETRIC TEST

Empty Mold & Collar .05838
Mold w/Soil .02663
Compacted Vol. of Soil .03175 cu. ft.

% Moisture: Wt. Wet Soil (g) ____
Wt. Dry Soil (g) ____
Wt. Water (g) ____

$$\left\{\frac{\text{Wt. Water (g)}}{\text{Wt. Dry Soil (g)}}\right\} 100 = \_\_\_\_\ \%$$

Wet Density: $\frac{\text{Wet Wt. Soil (g)}}{\text{Volume x 453.6}}$ = ____ lb./cu. ft.

Dry Density: $\left\{\frac{\text{Wet Density}}{100 + \%\ \text{Moisture}}\right\} 100$ = ____ lb./cu. ft.

A.A.S.H.T.O. DENSITY DETERMINATION

% Moisture: Wt. Wet Soil (g) ____
Wt. Dry Soil (g) ____
Wt. Water (g) ____

$$\left\{\frac{\text{Wt. Water (g)}}{\text{Wt. Dry Soil (g)}}\right\} 100 = \_\_\_\_\ \%$$

Wet Density: $\frac{\text{Wet Wt. Soil (g) x 30}}{453.6}$ = ____ = ____ lb./cu. ft.

Dry Density: $\left\{\frac{\text{Wet Density}}{100 + \%\ \text{Moisture}}\right\} 100$ = ____ lb./cu. ft.

PERCENT COMPACTION

$$\left\{\frac{\text{(Compacted Vol.) Dry Road Density}}{\text{Dry A.A.S.H.T.O. Density (In-Place Vol.)}}\right\} 100 \quad \frac{.03175}{.03200} = 99.2\ \%$$

FAIL

Signature: Inspector: E Good (12456)
Res. Engr.: ____

Figure 3 Example of Test 1-A "Short Test" (English units)

TEST 1A METRIC

M & T FORM 504M
REV. 11/94

NORTH CAROLINA DEPARTMENT OF TRANSPORTATION
DIVISION OF HIGHWAYS

FIELD AND A.A.S.H.T.O. DENSITY DETERMINATIONS

DATE 4-29-02

Project: 8.1234567 County: WAKE Test No. 1

Test Location & Type: 7+23 NBL (Sta; Lane;) RDWY (Rdwy. or Shldr.;) SUBG (Embank., Subg., or Base)

4 m RT (Dist. from C/L; Rt. or Lt.) -0- (Dist. below Subg. Elev.)

ROAD DENSITY DETERMINATION

Volume of Hole: 2nd Reading 1185
1st Reading 225
Difference 960 cm^3
Volume = $\frac{(cm^3)}{1,000,000}$ = ______ m^3

% Moisture: Wt. Wet Soil (g) ______
Wt. Dry Soil (g) ______
Wt. Water (g) ______
$\left\{\frac{\text{Wt. Water (g)}}{\text{Wt. Dry Soil (g)}}\right\}$ 100 = ______ %

Wet Density: $\frac{\text{Wet Wt. Soil (kg)}}{\text{Volume } (m^3)}$ ______ = ______ kg/m^3

Dry Density: $\left\{\frac{\text{Wet Density}}{100 + \text{\% Moisture}}\right\}$ 100 ______ = ______ kg/m^3

VOLUMETRIC TEST

Empty Mold & Collar 1570
Mold w/Soil 605
Compacted Vol. of Soil 965 cm^3

A.A.S.H.T.O. DENSITY DETERMINATION

% Moisture: Wt. Wet Soil (g) ______
Wt. Dry Soil (g) ______
Wt. Water (g) ______
$\left\{\frac{\text{Wt. Water (g)}}{\text{Wt. Dry Soil (g)}}\right\}$ 100 ______ = ______ %

Wet Density: $\frac{\text{Wet Wt. Soil (kg)}}{\text{Volume } (m^3)}$ = ______ = ______ kg/m^3

Dry Density: $\left\{\frac{\text{Wet Density}}{100 + \text{\% Moisture}}\right\}$ 100 ______ = ______ kg/m^3

PERCENT COMPACTION

$\left\{\frac{\text{(Compacted Vol.) Dry Road Density}}{\text{Dry A.A.S.H.T.O. Density (In-Place Vol.)}}\right\}$ 100 $\frac{965}{960}$ = 100.5 %

PASS

Volume of 1/30 ft^3 mold = .000944 m^3
Volume of 3/40 ft^3 mold = .002124 m^3
Volume of 18" ring = depth (m) x .169474015 (m^3/m)
cm^3 ÷ 1,000,000 = m^3

Figure 4 Example of Test 1-A “Short Test” (metric units)

SECTION 6 – DENSITY TEST 1

Also referred to as the "long test", Test 1 calculates percent compaction using values of unit weights, and requires weighing and drying steps. The proper steps should be followed to reduce the possibility of error.

Equipment Needed

The following equipment is necessary for performing Density Test 1.

- Volumeter
- 3-inch auger
- Large Spoon
- 50-pound weight
- 50-pound saddle weight for volumeter
- Soil Pan
- Pie plate (9" x 1 ½")
- Scales
- Small Spatula
- Frying pan
- Steel straight edge
- Compaction mold (1/30 ft^3)
- Sample extractor
- Compaction rammer (5 ½ pounds, 12-inch drop)
- Water container (i.e. small squirt bottle or graduated cylinder)
- Water
- Gas burner
- Square tip shovel

Determining the In-place Dry Density

All loose soil is removed from the surface of the layer and an area about 15 inches square is brought to a smooth, flat and approximately level surface by scraping with a steel straight edge or other suitable instrument.

The volumeter is placed on the smoothed surface of the soil, and a 50-pound saddle weight is placed on top of the volumeter. Air is applied to a pressure of 4-p.s.i. and an initial reading is taken. (This is the actual reading on the volumeter scale before the soil is removed). A mark is made on the soil surface tracing the outside of the volumeter base so that it may be placed in the same place after removal of soil.

A hole is made in the center of the circle on the volumeter base approximately four inches in diameter and six inches deep. The soil is removed and placed in a container for weighing and for determination of moisture content. It is, of course, important that all of the soil that is removed from the hole be placed in the container.

The volumeter is placed over the hole in the same position as when the initial reading was taken and the volume of the hole measured. The 50-pound saddle weight and the 4-p.s.i. air pressure shall be applied in the same manner as described for determining the initial reading. The difference between the second reading and the first reading is the volume of the hole in cubic feet. In order to obtain the desired accuracy, the volume of the test hole should not be less than 0.0275 cubic feet.

The soil that was removed from the hole is weighed and its moisture content determined by drying a sample weighing 300-grams. Care must be exercised in drying the sample to avoid overheating. Overheating a soil sample may affect the moisture content. To prevent overheating, the soil shall be dried over a low flame and shall be frequently stirred. The sample shall be removed from the flame immediately when it appears to be dry. The dry weight of the soil removed from the hole can then be determined. And, knowing the volume occupied by the soil, as measured with volumeter, the in-place density in pounds per cubic feet of the compacted soil can be calculated.

The in-place density of the soil is calculated by use of the following formula:

$$\text{Wet Density (lb./cu. ft.)} = \frac{\text{Wet Wt. of Soil (grams)}}{453.6 \times \text{Vol. of Hole}}$$

$$\text{Moisture Content} = \frac{(\text{Wet Wt.} - \text{Dry Wt.}) \times 100 = \%\ \text{Moisture}}{\text{Dry Wt.}}$$

$$\text{Dry Density (lb./cu. ft.)} = \left(\frac{\text{Wet Density}}{100 + \text{Moisture Content}}\right) \times 100$$

Determining the Maximum Dry Density

The expression “AASHTO Method T-99” refers to the description of a testing procedure, adopted as a standard by the American Association of State Highway and Transportation Officials, for compacting a sample of soil to determine its maximum dry density. The moisture content at which this maximum dry density is obtained is referred to as the “optimum moisture content” of the soil. This maximum dry density is also referred to as the “AASHTO Density”. All references to AASHTO T-99 in these procedures are to the test method adopted by AASHTO in 1993 (designated as AASHTO T-99-93). The use of a tapered mold is permitted.

The test procedure outlined below is a modification of the AASHTO Test Method T-99 for field use in that the soil is compacted at a moisture content estimated to be the optimum for that soil. As previously mentioned, an experienced operator can determine the optimum moisture of a soil by visual inspection within a narrow range in moisture content $\pm$2%, which is within the variation acceptable in practice. In order to simplify the compaction test procedure for field use, the standard procedure is revised to eliminate the necessity of running the entire moisture-density curve. (See Section 4, "Determination of Optimum Moisture")

Modified Moisture-Density Test

The soil used in determining the in-place density is also used in performing the compaction test. The portion of soil used in determining the moisture content of the soil is discarded and if more soil is needed it may be obtained from the sides of the hole uniformly from top to bottom. Approximately four to five pounds of soil are sufficient for completing the test.

The soil should be mixed and kneaded until the largest clod (not aggregate) does not exceed approximately ¼-inch in size as determined by visual inspection. Any aggregate present in the soil should be mixed uniformly and used in both the moisture and AASHTO Density Determination. The mass of soil is now examined visually for the correct moisture content. If it appears too wet, the soil is dried to approximately optimum as determined by visual inspection. If it appears too dry, water is mixed with it uniformly until estimated optimum moisture is obtained.

The prepared soil is divided into three parts and compacted in the mold in three approximately equal layers. The exact amount of soil in each part should be such that when compacted, all three parts will fill the mold (excluding the collar) to a point not to exceed ½ inches above the top, which is then struck off with the steel straight edge.

The compaction is performed with a compaction rammer weighing 5-½ pounds with a12-inch drop. Twenty-five blows of the rammer are applied to each of the three layers. The mold shall be placed on a 50-pound weight, pavement or on a similar rigid base while compacting. After the compacted soil is struck off with the steel straight edge, it shall be extracted from the mold, weighed and split to obtain 300 grams or more of soil in order to determine the moisture content. The same precautions should be observed in drying the sample as pointed out previously in this procedure. The weight and moisture content are determined and the dry density is calculated by use of the following formulas:

$$\text{Wet Density (lb./cu. ft.)} = \frac{\text{Wt. of Wet Soil in grams} \times 30}{453.6}$$

$$\text{Moisture Content} = \frac{\text{Wet Weight - Dry Weight} \times 100}{\text{Dry Weight}}$$

$$\text{Dry Density (lb./cu. ft.)} = \frac{(\text{Wet Density}) \times 100}{(100 + \text{Moisture Content})}$$

$$\text{Degree of Compaction (\%)} = \frac{(\text{Dry Density of Soil In-Place}) \times 100}{(\text{Dry Density of Soil Compacted in Mold})}$$

The constant 30 comes from the fact that, in computing the wet density we use a 1/30 cubic foot mold. The weight of material in the mold is multiplied by a factor of 30 which is the reciprocal of 1/30.

Step-by-step Procedure for Performing Test 1

NOTE: All volumeter readings require 4-psi water pressure; use M&T Form 504 to record your results.

1. Level the electronic scale.
2. Verify that the 2,000-gram weight reads as 2,000 grams on the scale, with a ±1-gram tolerance.
3. Weigh the empty mold and record.
4. Prepare a test site by smoothing the surface.
5. Level the plate on the test site.
6. Scribe around the edges of the plate, marking the volumeter valve location.
7. Take the first or "flat" reading.
8. Dig the test hole, starting off with a spoon and continue with an auger. Soil should be collected on the soil pan.
9. When hole is finished, remove loose soil particles from the hole and the plate and include them with the soil collected in step 6.
10. Check for sharp edges in the hole. If there are sharp edges, move to another location and repeat steps 1-8.
11. Take a second reading with the volumeter, positioning the valve at the marked location. The difference is the volume of the hole occupied by the removed soil.
12. If the difference between the second and the first reading is such that the volume of the hole is less than 0.02750 ft^3, the hole is too small. Remove additional soil and repeat steps 8-10.
13. Clean off excess soil from the auger and spoon, and include them with the soil in the soil pan.
14. Place all soil in the pie plate. Record the weight of the soil.
15. Place the soil back in the soil pan, and mix the soil until it has uniform water content.
16. Obtain 300 grams of soil. This is the sample for determining the in-place moisture content.
17. Dry the soil. When using a burner, be sure not to overheat the soil.
18. Weigh the dry soil and record.
19. Remove additional soil from the hole and place in the soil pan.
20. Break up and pulverize the soil.
21. Check for optimum moisture using the "squeeze" method.
22. Dry or add water to the soil as necessary, and mix for uniform water content. Repeat step 14-15 until optimum water content is obtained.
23. Place a first layer in the mold.
24. Apply compactive effort; apply the 25th blow in the center and check for the "penny print."
25. Place a second layer in the mold and apply compactive effort.

26. Place a third layer in the mold and apply compactive effort.
27. Scribe around the top(third) layer and then remove the mold collar.
28. The top of the third layer must be ¼ to ½ inches above the top of the mold.
29. Scrape off the excess soil with the straight edge until the surface is flush with the top of the mold.
30. Weigh the mold with the soil and record the weight.
31. Extract the soil pill with the sample extractor.
32. Using the straight edge, split the soil pill down the middle lengthwise.
33. Obtain 300 grams of soil from the scrapings. This is the sample for determining the soil's optimum moisture content.
34. Dry the soil. When using a burner, be sure not to overheat the soil.
35. Weigh the dry soil and record.
36. Using the data recorded, follow the steps on M&T Form 504 for obtaining percent compaction.

Sources of Error for Test 1

1. Density hole too small for accurate results.
2. Failure to thoroughly mix soil for moisture test.
3. Failure to keep volumeter in good working condition.
4. Cutting off more than ½ inch of soil after AASHTO mold is made.
5. Operator not understanding the significance of Optimum Moisture and Maximum Density.
6. Failure to remove all loose material in hole.
7. Dropping rammer more than 12 inches.
8. Scales not level.
9. Applying more or less than 25 blows to layer of soil.
10. Carelessness in removing soil from mold before weighing.
11. Test performed on "crust" of layer.

TEST 1 ENGLISH

NORTH CAROLINA DEPARTMENT OF TRANSPORTATION

M & T FORM 504
10-1-80

DIVISION OF HIGHWAYS

FIELD AND A.A.S.H.T.O. DENSITY DETERMINATIONS

Date: 4-29-02

Project: 8.123456 E County: WAKE Test No. 2

Test Location & Type: 11 + 91 NBL (Sta; Lane;) RDWY (Rdwy. or Shldr.;) SUBG. (Embank., Subg., or Base.)
11' RT (Dist. from C/L; Rt. or Lt.) -0- (Dist. below Subg. Elev.)

ROAD DENSITY DETERMINATION

Volume of Hole: 2nd Reading .03875
1st Reading .00675
Difference .03200 cu. ft.

VOLUMETRIC TEST

Empty Mold & Collar
Mold w/Soil
Compacted Vol. of Soil cu. ft.

% Moisture: Wt. Wet Soil (g) 300
Wt. Dry Soil (g) 268
Wt. Water (g) 32

$\left\{\frac{\text{Wt. Water (g)}}{\text{Wt. Dry Soil (g)}}\right\} 100 \; \frac{32}{268} = 11.9\ \%$

Wet Density: $\frac{\text{Wet Wt. Soil (g)}}{\text{Volume x 453.6}}$ (.03200) $\frac{1589}{14.5152} = 109.5$ lb./cu. ft.

Dry Density: $\left\{\frac{\text{Wet Density}}{100 + \%\text{ Moisture}}\right\} 100 \; \frac{109.5}{111.9} = 97.8$ lb./cu. ft.

A.A.S.H.T.O. DENSITY DETERMINATION

% Moisture: Wt. Wet Soil (g) 300
Wt. Dry Soil (g) 265
Wt. Water (g) 35

$\left\{\frac{\text{Wt. Water (g)}}{\text{Wt. Dry Soil (g)}}\right\} 100 \; \frac{35}{265} = 13.2\ \%$

Wet Density: $\frac{\text{Wet Wt. Soil (g) x 30}}{453.6}$ (1663) $= \frac{49890}{453.6} = 110.0$ lb./cu. ft.

Dry Density: $\left\{\frac{\text{Wet Density}}{100 + \%\text{ Moisture}}\right\} 100 \; \frac{110.0}{113.2} = 97.2$ lb./cu. ft.

PERCENT COMPACTION

$\left\{\frac{\text{(Compacted Vol.) Dry Road Density}}{\text{Dry A.A.S.H.T.O. Density (In-Place Vol.)}}\right\} 100 \; \frac{97.8}{97.2} = 100.6\ \%$

PASS

3504 Mold w/ soil
- <u>1841</u> Mold (empty)
1663 Soil

Signature: Inspector: I B GOODE (124?
Res. Engr.:

Figure 5 Example of Test 1 "Long Test" (English units)

TEST 1 METRIC

M & T FORM 504M
REV. 11/94

NORTH CAROLINA DEPARTMENT OF TRANSPORTATION
DIVISION OF HIGHWAYS

FIELD AND A.A.S.H.T.O. DENSITY DETERMINATIONS

DATE 4-29-02

Project: 8.1234567 County: WAKE Test No. 2

Test Location & Type: 10+13 NBL (Sta; Lane;) RDWY (Rdwy. or Shldr.;) SUBG. (Embank., Subg., or Base)
2 m RT (Dist. from C/L; Rt. or Lt.) -0- (Dist. below Subg. Elev.)

ROAD DENSITY DETERMINATION

Volume of Hole: 2nd Reading 1040
1st Reading 225
Difference 815 cm^3
Volume = $\frac{815 \ (cm^3)}{1,000,000}$ = 0.000815 m^3

VOLUMETRIC TEST

Empty Mold & Collar ____
Mold w/Soil ____
Compacted Vol. of Soil ____ cm^3

% Moisture: Wt. Wet Soil (g) 300
Wt. Dry Soil (g) 263
Wt. Water (g) 37

$\left\{\frac{\text{Wt. Water (g)}}{\text{Wt. Dry Soil (g)}}\right\} 100 =$ 14.1 %

Wet Density: $\frac{\text{Wet Wt. Soil (kg)}}{\text{Volume } (m^3)}$ $\frac{1.502}{0.000815}$ = 1842.9 kg/m^3

Dry Density: $\left\{\frac{\text{Wet Density}}{100 + \text{\% Moisture}}\right\} 100$ $\frac{1842.9}{114.1}$ = 1615.2 kg/m^3

A.A.S.H.T.O. DENSITY DETERMINATION

% Moisture: Wt. Wet Soil (g) 300
Wt. Dry Soil (g) 259
Wt. Water (g) 41

$\left\{\frac{\text{Wt. Water (g)}}{\text{Wt. Dry Soil (g)}}\right\} 100$ $\frac{41}{259}$ = 15.8 %

Wet Density: $\frac{\text{Wet Wt. Soil (kg)}}{\text{Volume } (m^3)}$ = 1.761 = 1865.5 kg/m^3

Dry Density: $\left\{\frac{\text{Wet Density}}{100 + \text{\% Moisture}}\right\} 100$ $\frac{1865.5}{115.8}$ = 1610.9 kg/m^3

PERCENT COMPACTION

$\left\{\frac{\text{Dry Road Density (Compacted Vol.)}}{\text{Dry A.A.S.H.T.O. Density (In-Place Vol.)}}\right\} 100$ $\frac{1615.2}{1610.9}$ = 100.3 %

PASS

Volume of 1/30 ft^3 mold = .000944 m^3
Volume of 3/40 ft^3 mold = .002124 m^3
Volume of 18" ring = depth (m) x .169474015 (m^3/m)
m^3 ÷ 1,000,000 = m^3

(123457)

3602 Mold w/ soil
- 1841 Mold (empty)
1761 Soil

Signature Inspector: I.B. GOOD
Res. Engr.: ____

Figure 6 Example of Test 1 "Long Test" (metric units)

SECTION 7 – DENSITY TEST 2

Test 2 is used to calculate the degree of compaction of embankments, subgrades or soil bases that contain or have been stabilized by an admixture of aggregate material (density Tests 1 and 1-A should not be used for this type of material). The procedure for Test 2 is outlined below.

Equipment Needed

The following equipment is necessary for the performance of Density Test 2.

Calibrated steel ring (18” outside diameter and 4 ½ inches to 9 inches deep)
Small pick
Scoop
Scales
Gas burner
Frying pan
Ruler
Straight edge (36 inches long)
Large Spoon
Bucket (10-quart capacity)
Compaction mold (3/40 cubic foot = 0.075 cubic foot volume)
Compaction rammer (5 ½-pounds, 12-inch drop)
Steel straight edge

Determining the In-place Dry Density

The calibrated steel ring is placed over the area to be tested and the material within the ring is carefully loosened with the pick and removed with the scoop. The material removed is placed in the bucket for weighing. As the material is removed, the ring is lowered to the full depth of the layer by lightly tapping the top of the ring with a wooden mallet or similar wooden object.

After all material has been removed, the ring is removed and the thickness of the layer is carefully measured to the nearest one-sixteenth by placing a straight edge across the top of the hole and taking five or more measurements along opposing diameters (Refer to Diagram 2).

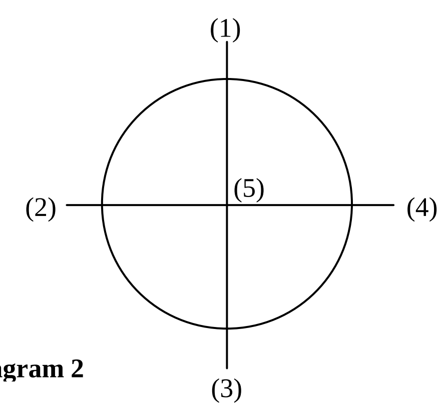

Diagram 2

From these measurements, the average depth of the hole is determined. Although the steel ring has an outside diameter of 18 inches, which theoretically would occupy a volume of 0.147 cubic feet per inch of depth, it has been found that its effective diameter is 18.3 inches, and it actually occupies a volume of 0.152 cubic feet per inch of depth. The volume in cubic feet occupied by the material is calculated by multiplying the average depth of the layer in meter by 0.152. Average depth of layer x 0.152 = cubic feet of material. The wet density of the layer is calculated by dividing the weight of the material removed by its volume.

$$\text{Wet Density (lb./cu. ft.)} = \frac{\text{Wet Wt. of Material (pounds)}}{\text{Volume of Material (cu. ft.)}}$$

The moisture content of the material is determined by weighing out a minimum of 1,000 grams of the material and drying it out over the gas burner. To prevent overheating, the soil shall be dried over a low flame and shall be frequently stirred. The sample shall be removed from the flame immediately when it appears to be dry. The moisture content in percentage of the dry material is calculated by the following formula:

$$\text{Moisture Content} = \frac{\text{(Wet Wt. - Dry Wt.)}}{\text{Dry Wt.}} \times 100$$

The dry density of the layer is calculated using the following formula:

$$\text{Dry Density (lb./cu. ft.)} = \frac{(\text{Wet Density}) \times 100}{(100 + \text{Moisture Content})}$$

Determining the Maximum Dry Density

The expression "AASHTO Method T-99" refers to the description of a testing procedure, adopted as a standard by the American Association of State Highway and Transportation Officials for compacting a sample of soil to determine its dry density. The method, as described, has four alternate procedures that provide for soils with and without coarse aggregate, compacted in six-inch and four-inch diameter molds. The test not only determines the greatest density of which the soil may be compacted by the prescribed compaction effort, but determines the proper moisture content required to obtain this maximum density, called the "Optimum Moisture" content. This requires that a complete moisture density curve be run on the material. The field compaction test described below is a modification of the standard test in that the soil is compacted in the mold only once at a moisture content estimated to be optimum. It has been found that an experienced operator using visual inspection can estimate the optimum moisture content. The optimum moisture can be estimated within a narrow range, which is within the variation acceptable in practice. In order to simplify the compaction test procedure for field use, the standard procedure is revised to eliminate the need of running the entire moisture density curve (See Section 4, Determination of Optimum Moisture).

A representative portion of the material obtained from the in-place density test is used in the field compaction test. Since the volume of the material obtained from the in-place density test is more than is needed for the field compaction test, it must be thoroughly mixed and reduced in quantity by quartering. It is very important that the portion selected for the field compaction test contain a representative amount of coarse aggregate, as the quantity of this fraction influences the unit weight (density) appreciably. About 12 pounds of soil-aggregate will be required for the test. If the material appears wetter than optimum, it should be dried to estimated optimum; if too dry, water should be uniformly mixed with the material until the estimated optimum moisture is obtained.

The prepared soil-aggregate is divided in three parts of about four pounds each and compacted in the 3/40 cubic foot mold in three approximate equal layers. The amount of soil-aggregate in each part should be such that all three parts will fill the mold, after compaction, to a point not to go over the top, which is struck off with a steel straight edge.

The compaction is done with the compaction rammer that weighs 5-½ pounds and drops 12 inches. Each of the three layers is compacted by 56 blows of the rammer with the mold placed on a 50-pound weight or pavement or similar rigid base while compacting.

After the compacted soil aggregate is struck off with the steel straight edge, it shall be extracted from the mold, weighed and split to obtain 1,000 grams or more of soil in order to determine the moisture content. The same precautions should be observed in drying the sample as pointed out previously in this procedure. The weight and moisture content are determined and the dry unit weight (dry density) and degree of compaction are calculated by the following formulas:

$$\text{Wet Density (lb./cu. ft.)} = \frac{\text{Wt. of Wet Soil-Aggregate (grams)} \times 13.33}{453.6}$$

$$\text{Moisture Content} = \frac{(\text{Wet Wt.} - \text{Dry Wt.})}{(\text{Dry Wt.})} \times 100$$

$$\text{Dry Density (lb./cu. ft.)} = \frac{(\text{Wet Density})}{(100 + \text{Moisture Content})} \times 100$$

$$\text{Degree of Compaction \%} = \frac{(\text{Dry Density of Soil-Aggregate In-Place})}{(\text{Dry Density of Compacted Soil-Aggregate})} \times 100$$

The constant 13.33 comes from the fact that, in computing the wet density we use a 3/40 cubic foot mold. The weight of material in the mold is multiplied by a factor of 13.33 which is the reciprocal of 3/40 or 40 ÷3 = 13.3333.

The constant 453.6 is a conversion factor that converts grams to pounds. All weights recorded during the test procedure are in grams, but the final answer is recorded in pounds; therefore, the wet weight of the soil is divided by 453.6 to convert the units from grams to pounds (453.6 grams = 1 pound).

Step-by-step Procedure for Performing Test 2

1. Level the scale.
2. Verify that the 2,000-gram weight reads as 2,000 grams on the scale, with a ±1-gram tolerance.
3. Tare the bucket.
4. Place the sampling ring on the surface of the layer to be tested.
5. Using the pick loosen the material on the surface within the ring.
6. Remove the material and place in the bucket. Repeat 5-6 until bucket is full.
7. Weigh the material and record.
8. Dump the material on the ground (but do not discard!)
9. Lower the ring through the layer by lightly tapping the top of the ring with a wooden mallet or similar wooden object.
10. Repeat steps 4-7 until the ring rests on the top of the next layer.
11. Take five measurements of the depth of the hole: one at the center of the hole and at four points equally spaced along the edge of the hole (that is, a measuring point is 90 degrees from an adjacent measuring point). All measurements will be to the nearest 16th of an inch. Calculate the average of the 5 readings – this will be the "depth" of the hole used for calculations.
12. Using a shovel, thoroughly mix the material dumped on the ground in step 7.
13. Quarter down the material and re-mix. Do this twice (the purpose of quartering is to obtain a representative sample).
14. Obtain a 1,000-gram moisture sample. This is the sample for determining the in-place moisture content of the material.
15. Dry the soil. When using a burner, be sure not to overheat the soil.
16. Weigh the dry soil and record.
17. Obtain material from the quartered-down portion, and place in the soil pan until it is about 2/3 full.
18. Check for optimum moisture using the "squeeze" method.
19. Dry or add water to the soil as necessary, and mix for uniform water content. Repeat step 14-15 until optimum water content is obtained.
20. Place a first layer in the mold (NOTE: a 3/40 ft^3 mold should be used for this test).
21. Apply compactive effort (NOTE: For this test, apply 56 blows per layer); apply the 56th blow in the center and check for the "penny print."
22. Place a second layer in the mold and apply compactive effort.
23. Place a third layer in the mold and apply compactive effort.
24. Scribe around the top (third) layer and then remove the mold collar.
25. The top of the third layer must be ¼ to ½ inches above the top of the mold.
26. Scrape off the excess soil with the straight edge until the surface is flush with the top of the mold. Fill in voids with fine material and re-smooth the surface.

27. Weigh the mold with the soil and record the weight.
28. Extract the soil pill.
29. Using the straight edge, split the soil pill down the middle lengthwise.
30. Obtain 1,000 grams of material from the scrapings. This is the sample for determining the soil's moisture content.
31. Dry the soil. When using a burner, be sure not to overheat the soil.
32. Weigh the dry soil and record.
33. Using the data recorded, follow the steps on M&T Form 504 for obtaining percent compaction.

<u>Sources of Error for Test 2</u>

1. Failure to take representative sample for making AASHTO mold.
2. Carelessness in measuring depth of density hole.
3. Scales not level.
4. Carelessness in drying soil.
5. Carelessness in removing soil from mold before weighing.
6. Applying more or less than 56 blows to layer of material.
7. Operator not understanding the significance of <u>Optimum Moisture</u> and <u>Maximum Density</u>

TEST 2 ENGLISH

NORTH CAROLINA DEPARTMENT OF TRANSPORTATION — M & T FORM 504 10-1-80

DIVISION OF HIGHWAYS

FIELD AND A.A.S.H.T.O. DENSITY DETERMINATIONS

Date: 4-29-02

Project: 8.123456 E County: WAKE Test No. 1

Test Location & Type:
21+51 NBL (Sta; Lane;) RDWY (Rdwy. or Shldr.;) STAB. SUBG. (Embank., Subg., or Base.)
11' RT (Dist. from C/L; Rt. or Lt.) —0— (Dist. below Subg. Elev.)

ROAD DENSITY DETERMINATION

Volume of Hole: 2nd Reading ______
1st Reading ______
Difference ______ cu. ft.

VOLUMETRIC TEST

Empty Mold & Collar ______
Mold w/Soil ______
Compacted Vol. of Soil ______ cu. ft.

% Moisture: Wt. Wet Soil (g) 1000
Wt. Dry Soil (g) 911
Wt. Water (g) 89

$\left\{\frac{\text{Wt. Water (g)}}{\text{Wt. Dry Soil (g)}}\right\} 100 \quad \frac{89}{911} = 9.8\ \%$

Wet Density: $\frac{\text{Wet Wt. Soil (g)}}{\text{Volume x } \cancel{453.6}}$ $\frac{115.1}{0.8151}$ = 141.2 lb./cu. ft.

5.3625 × .152

Dry Density: $\left\{\frac{\text{Wet Density}}{100 + \%\ \text{Moisture}}\right\} 100 \quad \frac{141.2}{109.8}$ = 128.6 lb./cu. ft.

A.A.S.H.T.O. DENSITY DETERMINATION

% Moisture: Wt. Wet Soil (g) 1000
Wt. Dry Soil (g) 907
Wt. Water (g) 93

$\left\{\frac{\text{Wt. Water (g)}}{\text{Wt. Dry Soil (g)}}\right\} 100 \quad \frac{93}{907} = 10.3\ \%$

4853 × 13.33

Wet Density: $\frac{\text{Wet Wt. Soil (g) x } \cancel{30}}{453.6}$ = $\frac{64690.49}{453.6}$ = 142.6 lb./cu. ft.

Dry Density: $\left\{\frac{\text{Wet Density}}{100 + \%\ \text{Moisture}}\right\} 100 \quad \frac{142.6}{110.3}$ = 129.3 lb./cu. ft.

PERCENT COMPACTION

$\left\{\frac{\text{(Compacted Vol.) Dry Road Density}}{\text{Dry A.A.S.H.T.O. Density (In-Place Vol.)}}\right\} 100 \quad \frac{128.6}{129.3}$ = 99.5 %

FAIL

WT(LBS)	DEPTH OF HOLE
45.1	$5\frac{4}{16}$
44.1	$5\frac{7}{16}$
5.9	$5\frac{9}{16}$
115.1	$5\frac{3}{16}$
	$5\frac{6}{16}$
	$25\frac{29}{16} = 26.8125$

AVERAGE DEPTH = 5.3625

Signature: Inspector: (12345)
Res. Engr.: ______

Figure 7 Example of Test 2 (English units)

TEST 2 METRIC

M & T FORM 504M
REV. 11/94

NORTH CAROLINA DEPARTMENT OF TRANSPORTATION
DIVISION OF HIGHWAYS

FIELD AND A.A.S.H.T.O. DENSITY DETERMINATIONS

DATE 4-29-02

Project: 8.1234567 County: WAKE Test No. 1

Test Location & Type: 1+250 NBL (Sta; Lane;) RDWY (Rdwy. or Shldr.;) STAB. SUBG. (Embank., Subg., or Base)
2.5 M RT (Dist. from C/L; Rt. or Lt.) 0 (Dist. below Subg. Elev.)

ROAD DENSITY DETERMINATION

Volume of Hole: 2nd Reading ______
1st Reading ______
Difference ______ cm^3
Volume = ______ (cm^3) / 1,000,000 = ______ m^3

VOLUMETRIC TEST

Empty Mold & Collar ______
Mold w/Soil ______
Compacted Vol. of Soil ______ cm^3

% Moisture: Wt. Wet Soil (g) 1000
Wt. Dry Soil (g) 903
Wt. Water (g) 97

$\left\{\frac{\text{Wt. Water (g)}}{\text{Wt. Dry Soil (g)}}\right\} 100 = 10.7\ \%$

Wet Density: $\frac{\text{Wet Wt. Soil (kg)}}{\text{Volume } (m^3)}$ $\frac{37.97}{(0.1026)(0.169474015)}$ = 2183.7 kg/m^3

Dry Density: $\left\{\frac{\text{Wet Density}}{100 + \text{\% Moisture}}\right\} 100$ $\frac{2183.7}{110.7}$ = 1972.6 kg/m^3

A.A.S.H.T.O. DENSITY DETERMINATION

% Moisture: Wt. Wet Soil (g) 1000
Wt. Dry Soil (g) 905
Wt. Water (g) 95

$\left\{\frac{\text{Wt. Water (g)}}{\text{Wt. Dry Soil (g)}}\right\} 100$ $\frac{95}{905}$ = 10.5 %

Wet Density: $\frac{\text{Wet Wt. Soil (kg)}}{\text{Volume } (m^3)}$ = $\frac{4.629}{0.002124}$ = 2179.3 kg/m^3

Dry Density: $\left\{\frac{\text{Wet Density}}{100 + \text{\% Moisture}}\right\} 100$ $\frac{2179.3}{110.5}$ = 1972.3 kg/m^3

PERCENT COMPACTION

$\left\{\frac{\text{(Compacted Vol.) Dry Road Density}}{\text{Dry A.A.S.H.T.O. Density (In-Place Vol.)}}\right\} 100$ $\frac{1972.6}{1972.3}$ = 100.0 %

PASS

Volume of 1/30 ft^3 mold = .000944 m^3
Volume of 3/40 ft^3 mold = .002124 m^3
Volume of 18" ring = depth (m) x .169474015 (m^3/m)
cm^3 ÷ 1,000,000 = m^3

WT (KG)	DEPTH OF HOLE (m)
19.28	0.1032
16.33	0.1016
2.36	0.1000
	0.1048
37.97	0.1032

AVERAGE DEPTH = 0.1026 m

Signature Inspector: [signature] (12?

Res. Engr.: ______

Figure 8 Example of Test 2 (metric units)

SECTION 8 – DENSITY TEST 3

When the base course material is predominantly soil, the procedure outlined under Density Test 1 or 1-A shall be used. Coarse aggregate base course, that is, those soils having a high percentage of stone or gravel, will require a different procedure for the measurement of the degree of compaction. As in the determination of the degree of compaction of embankments and subgrades, the in-place density of each base course layer must be measured. The maximum dry density of Aggregate Base Course (ABC) will not be determined in the field. The Soils Laboratory performs an AASHTO T-180 moisture-density curve annually on ABC from quarries that are approved to sale material to the Department. The maximum dry density (or Unit Weight) and optimum moisture are maintained in a database and can be accessed by visiting the Materials and Tests website or calling the Soils Laboratory. When ABC material used on a particular project comes from a known source or quarry, the value of its maximum dry density as furnished by the Soils Laboratory will be reasonably constant for that source. However, if the date since previous AASHTO T-180 test was performed is approaching 12 months, a Technician should routinely visit the Materials and Tests website to monitor the Unit Weight. Once the Unit Weight is updated, the new maximum dry density and optimum moisture content should be used as the Target Density. If a Contractor elects to use ABC from more than one source care should be taken to avoid mixing the materials. While the ABC material is being placed a method of identifying the location of each material is necessary since the Unit Weight and optimum moisture of each material may be different.

Equipment Needed

The following equipment is necessary for the performance of Density Test 3.

- Calibrated steel ring (18” outside diameter and 4 ½ inches to 9 inches deep)
- Small pick
- Scoop
- Scales (min. 12 kg capacity)
- Gas burner
- Frying pan
- Rule
- Straight edge (36 inches long)
- Large Spoon
- Bucket (10-quart capacity)

Determining the In-place Dry Density

The calibrated steel ring is placed over the area to be tested and the base course material within the ring is carefully loosened with a pick and removed with the scoop. The material is placed in the bucket for weighing. As the material is removed, the ring is lowered to the full depth of the layer by lightly tapping the top of the ring with a wooden mallet, or similar wooden object. After all material has been removed, the ring is removed from the base course layer and the thickness is carefully measured to the nearest one-sixteenth of an inch by placing a straight edge across the top of the hole and taking five or more measurements along opposing diameters (Refer to Diagram 3).

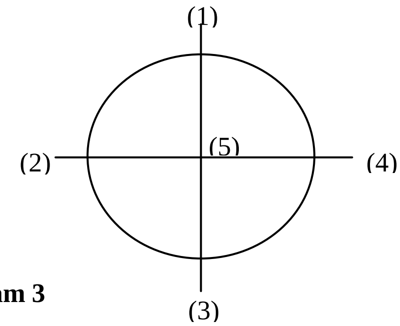

Diagram 3

From these measurements the average thickness of the layer is determined. Although the steel ring has an outside diameter of 18 inches, which theoretically would occupy a volume of 0.147 cubic feet per inch of depth, it has been found that its effective diameter is 18.3 inches, and it actually occupies a volume of 0.152 cubic feet per inch of depth. The volume in cubic feet occupied by the material is calculated by multiplying the average depth of the layer in inches by 0.152. Average depth of layer x 0.152 = cubic feet of base material. The wet density of the base course is calculated by dividing the weight of the material removed by its volume.

$$\text{Wet Density} = \frac{\text{Wet Wt. of Material in Pounds}}{\text{Volume of Material in Cubic Feet}}$$

The moisture content of the base material is determined by weighing out a minimum of 1,000 grams of the material and drying it out over the gas burner. Care must be exercised in drying the sample to avoid overheating. Overheating will result in an erroneous value of the moisture content. To prevent overheating, the aggregate mixture shall be dried over a low flame and shall be frequently stirred. The sample shall be removed from the flame immediately when it appears to be dry. The moisture content in percent of the dry material is calculated by the following formula:

$$\text{Moisture Content} = \frac{(\text{Wet Wt.} - \text{Dry Wt.})}{(\text{Dry Wt.})} \times 100$$

The dry density of the base course is calculated using the following formula:

$$\text{Dry Density} = \frac{(\text{Wet Density})}{(100 + \text{Moisture Content})} \times 100$$

$$\text{Degree of Compaction \%} = \frac{(\text{Dry Density of Aggregate In-Place})}{(\text{Dry Density by Laboratory Test})} \times 100$$

Step-by-step Procedure for Performing Test 3

1. Level the scale.
2. Verify that the 2,000-gram weight reads as 2,000 grams on the scale, with a ±1-gram tolerance.
3. Tare the bucket.
4. Place the sampling ring on the surface of the layer to be tested.
5. Using the pick loosen the material on the surface within the ring.
6. Remove the material and place in the bucket. Repeat 5-6 until bucket is full. NOTE: Halfway through the layer, perform additional steps 6a to 6f for determining the in-place moisture content.

6a. Tare the pie pan.
6b. Thoroughly mix the loose material in the ring.
6c. Obtain a 1,000-gram moisture sample. This is the sample for determining the in-place moisture content of the material.
6d. Dry the soil. When using a burner, be sure not to overheat the soil.
6e. Weigh the dry soil and record.
6f. Tare the bucket.

7. Weigh the material and record.
8. Dump the material on the ground (<u>but do not discard!)</u>
9. Lower the ring through the layer by lightly tapping the top of the ring with a wooden mallet or similar wooden object.
10. Repeat steps 4-7 until the ring rests on the top of the next layer (the subgrade).
11. Remove the ring carefully.
12. Move to the side of the hole any loose material that has fallen during ring removal.
13. Take five measurements of the depth of the hole: one at the center of the hole and at four points equally spaced along the edge of the hole (that is, a measuring point is 90 degrees from an adjacent measuring point). All measurements will be to the nearest 16^{th} of an inch. Calculate the average of the 5 readings – this will be the "depth" of the hole used for calculations.
14. Using the data recorded, follow the steps on M&T Form 504 for obtaining percent compaction.

Sources of Error for Test 3

1. Carelessness in measuring depth of density hole.
2. Forcing steel ring into base course.
3. Failure to mix material from hole before taking moisture sample.
4. Failure to place straight edge down to flat surface of base course when measuring depth of density hole.
5. Scales not level.

TEST 3 ENGLISH

NORTH CAROLINA DEPARTMENT OF TRANSPORTATION

M & T FORM 504
10-1-80

DIVISION OF HIGHWAYS

FIELD AND A.A.S.H.T.O. DENSITY DETERMINATIONS

Date: 4-29-02

Project: 8.123456 E County: WAKE Test No. 1

Test Location & Type: 29+15 NBL (Sta; Lane;) RDWY (Rdwy. or Shldr.;) BASE (Embank., Subg., or Base.)
8' RT (Dist. from C/L; Rt. or Lt.) —0— (Dist. below Subg. Elev.)

ROAD DENSITY DETERMINATION

Volume of Hole: 2nd Reading ______
1st Reading ______
Difference ______ cu. ft.

VOLUMETRIC TEST

Empty Mold & Collar ______
Mold w/Soil ______
Compacted Vol. of Soil ______ cu. ft.

% Moisture: Wt. Wet Soil (g) 1000
Wt. Dry Soil (g) 956
Wt. Water (g) 44

$\left\{\frac{\text{Wt. Water (g)}}{\text{Wt. Dry Soil (g)}}\right\} 100 \quad \frac{44}{956} = 4.6\ \%$

Wet Density: $\frac{\text{Wet Wt. Soil (g)}}{\text{Volume x 453.6}} \quad \frac{177.3}{1.2217} = 145.1$ lb./cu. ft.

8.0375 x .152

Dry Density: $\left\{\frac{\text{Wet Density}}{100 + \%\ \text{Moisture}}\right\} 100 \quad \frac{145.1}{104.6} = 138.7$ lb./cu. ft.

A.A.S.H.T.O. DENSITY DETERMINATION

% Moisture: Wt. Wet Soil (g) ______
Wt. Dry Soil (g) ______
Wt. Water (g) ______

$\left\{\frac{\text{Wt. Water (g)}}{\text{Wt. Dry Soil (g)}}\right\} 100$ ______ = ______ %

Wet Density: $\frac{\text{Wet Wt. Soil (g) x 30}}{453.6}$ = ______ = ______ lb./cu. ft.

Dry Density: $\left\{\frac{\text{Wet Density}}{100 + \%\ \text{Moisture}}\right\} 100$ GARNER QUARRY 137.6 lb./cu. ft.

PERCENT COMPACTION

$\left\{\frac{\text{(Compacted Vol.) Dry Road Density}}{\text{Dry A.A.S.H.T.O. Density (In-Place Vol.)}}\right\} 100 \quad \frac{138.7}{137.6} = 100.8\ \%$

PASS

WT (LBS)	DEPTH OF HOLE (IN)
36.9	$8\frac{2}{16}$
32.0	$7\frac{15}{16}$
2.2	8.0
39.6	$7\frac{15}{16}$
38.4	$8\frac{3}{16}$
28.2	
177.3	$38\frac{35}{16} = 40.1875$

AVERAGE DEPTH = 8.0375

Signature: Inspector: [signature] (12345)
Res. Engr.: ______

Figure 9 Example of Test 3 “Ring Test“ (English units)

TEST 3 METRIC

M & T FORM 504M
REV. 11/94

NORTH CAROLINA DEPARTMENT OF TRANSPORTATION
DIVISION OF HIGHWAYS

FIELD AND A.A.S.H.T.O. DENSITY DETERMINATIONS

DATE 4-29-02

Project: 8.1234567 County: WAKE Test No. 1

Test Location & Type: 1+131 NBL (Sta; Lane;) RDWY (Rdwy. or Shldr.;) BASE (Embank., Subg., or Base)
3.2 M RT (Dist. from C/L; Rt. or Lt.) -0- (Dist. below Subg. Elev.)

ROAD DENSITY DETERMINATION

Volume of Hole: 2nd Reading ______
1st Reading ______
Difference ______ cm^3
Volume = ______ (cm^3) / 1,000,000 = ______ m^3

VOLUMETRIC TEST

Empty Mold & Collar ______
Mold w/Soil ______
Compacted Vol. of Soil ______ cm^3

% Moisture: Wt. Wet Soil (g) 1000
Wt. Dry Soil (g) 940
Wt. Water (g) 60

$\left\{\frac{\text{Wt. Water (g)}}{\text{Wt. Dry Soil (g)}}\right\}$ 100 = 6.4 %

Wet Density: $\frac{\text{Wet Wt. Soil (kg)}}{\text{Volume (m}^3\text{)}}$ $\frac{87.25}{0.20862\ (0.169474015}$ = 2467.8 kg/m^3

Dry Density: $\left\{\frac{\text{Wet Density}}{100 + \text{\% Moisture}}\right\}$ 100 $\frac{2467.8}{106.4}$ = 2319.4 kg/m^3

A.A.S.H.T.O. DENSITY DETERMINATION

% Moisture: Wt. Wet Soil (g) ______
Wt. Dry Soil (g) ______
Wt. Water (g) ______

$\left\{\frac{\text{Wt. Water (g)}}{\text{Wt. Dry Soil (g)}}\right\}$ 100 ______ = ______ %

Wet Density: $\frac{\text{Wet Wt. Soil (kg)}}{\text{Volume (m}^3\text{)}}$ = ______ = ______ kg/m^3

Dry Density: $\left\{\frac{\text{Wet Density}}{100 + \text{\% Moisture}}\right\}$ 100 RDU QUARRY = 2308.3 kg/m^3

PERCENT COMPACTION

$\left\{\frac{\text{(Compacted Vol.) Dry Road Density}}{\text{Dry A.A.S.H.T.O. Density (In-Place Vol.)}}\right\}$ 100 $\frac{2319.4}{2308.3}$ = 100.5 %

PASS

Volume of 1/30 ft^3 mold = .000944 m^3
Volume of 3/40 ft^3 mold = .002124 m^3
Volume of 18" ring = depth (m) x .169474015 (m^3/m)
m^3 + 1,000,000 = m^3

K	(KG)	DEPTH OF HOLE (m)
9.48	10.89	0.2032
10.48	10.80	0.2113
11.16	11.16	0.2127
1.00		0.2111
10.98	87.25	0.2048
10.80		

AVERAGE DEPTH = 0.20862

12345

Signature Inspector: [signature]

Res. Engr.: ______

Figure 10 Example of Test 3 "Ring Test" (metric units)

SECTION 9 - FIELD APPLICATION OF TEST METHODS

Except as noted elsewhere in this section, the "squeeze" test will be used to estimate the optimum moisture content of a soil. This method, if properly performed, can provide a value of optimum moisture content close to that obtained from a moisture-density curve performed on the same material. By using this method, a Technician can rapidly determine if a Contractor is placing material at a moisture content that meets the requirements of the Specifications which currently states:

> *Increase or decrease moisture content of the material before compacting to produce the maximum density that will provide a stable grade*

An important responsibility of the Technician is to monitor the construction process to ensure compliance with this section of the Specifications. Since the optimum moisture content of a soil may change many times within any given area (due to changes in the soil type), to specify a definite range of moisture content would be difficult to enforce or document. The "squeeze" test on the other hand provides a rapid means of continually monitoring moisture content of the material as it is being placed. However, it must be performed properly, and if the Technician has reason to question if the material is being placed at a moisture content outside the requirements of the Specifications, then he/she shall perform the necessary test or tests to support his/her estimate.

In the past, we have encountered a great deal of difficulty using the "squeeze" test for estimating optimum moisture. This difficulty may be due to a Technician's inability to perform the "squeeze" test properly but may also be due to the lack of a procedure to document the test and prove that the "squeeze" test results were reasonable. In order to aid the Technician in checking results, the following procedure will be used:

1. One (1) out of every fifteen (15) tests will be a comparison test which will consist of performing Test 1 (long test) and a moisture-density curve.
2. For small projects which require less than 15 density tests a minimum of one Test 1 with a moisture-density curve must be performed.
3. Test 1-A will be permitted for the remainder of the tests.
4. In questionable situations, the Technician should perform Test 1 and perform a moisture-density curve to assure that a reasonable accuracy in the "squeeze" test is being obtained.
5. The results of each comparison will be recorded in a field book and each comparison numbered.

The above procedure will serve as a record of the Technician's ability to estimate optimum and as an aid to the Technician in improving his/her ability to accurately estimate the optimum moisture content of a soil. The field book maintained by the Technician shall be kept as shown in Table 3. A section for this information can be designated in the Project Density Diary (refer to Section 11 in this manual).

Date	No.	Sta. Or Area Sample Obtained	Inspector	Test 1 Results: Estimated Optimum Moisture and Dry Density	Moisture-Density Curve: Optimum Moisture and Max. Dry Density

Table 3

It shall be the responsibility of the Technician and the Resident Engineer to ensure the values obtained by this comparison are reasonably close. If the values obtained are not reasonably close, then the Technician shall review his/her method of estimating optimum moisture by the "squeeze" test, and make the necessary adjustments. If difficulty is encountered in obtaining reasonably close results, the Technician shall notify the Resident Engineer who in turn will request assistance from the Soils Laboratory.

Provided a project meets certain requirements (described below), the Resident Engineer may, in lieu of the "One Point Proctor", use the following procedures:

1. Embankment areas constructed of borrow material - At the time samples of borrow material are submitted to the Soils Laboratory for approval, the Resident Engineer may request to develop moisture-density curves and use them in lieu of running the "One Point Proctor" (AASHTO portion of the long test). This approval by the Soils Laboratory would only be given if the material is reasonably uniform in composition. Upon approval by the Soils Laboratory, the Resident Engineer would develop moisture-density curves and use them as a basis for determining optimum moisture content and maximum dry density (target density). It shall be the responsibility of the Resident Engineer to ensure that enough check curves are performed to determine if the material has changed significantly. Each moisture-density curve shall be numbered consecutively and the number shall be recorded on the density test report when it is used as the basis for the moisture determination.

2. Projects utilizing soil type base course material - The same procedures as outlined in number one above may be used.

3. Embankments constructed of excavated material of a uniform nature - If the Resident Engineer feels the material being excavated and placed in an embankment area is reasonably uniform, a moisture-density curve can be performed as described in number one above. The Resident Engineer must understand when following this procedure that it is his/her responsibility to ensure that enough moisture-density curves are performed to determine that the material has not significantly changed.

If any of the above three procedures are followed, the AASHTO Determination shown on the bottom of the test report (M&T Form 504) will not be computed for each test that is performed, but the value obtained from the moisture-density curve will be used, and it shall be noted on the report. The use of Procedures 1, 2, or 3 described above will not eliminate the necessity for the Technician to be able to perform the "squeeze" test properly. When utilizing this testing procedure, the Technician will be required to perform and record the results of one Test 1 (long test) with a moisture-density curve for every fifteen (15) soil density tests (described in Section 9 of this manual).

SECTION 10 - EQUIPMENT

Maintenance and Care of Equipment

1. *Scales* - Scales should be kept in box when not in use to prevent damage and accumulation of dirt. Scales should also be kept out of rain and extremely dusty conditions. CHARGE THE SCALE BATTERY OVERNIGHT AT LEAST ONCE EVERY WEEK (whether the device is used or not). Do not use any chargers for charging the battery other than the one that was issued with the device.

2. *Volumeter* - The volumeter should be protected against breakage and freezing temperatures. When the volumeter is not to be used for an extended period of time, remove the balloon, drain the water and clean the device prior to placing it in storage.

3. *Steel Density Rings* - The density rings should not be lowered into the base course by tapping with metal objects. The use of sledgehammers and other metal objects distorts the upper edge of the steel ring.

4. *Rammer* - Care should be exercised in compacting the top layer of soil in the mold to avoid striking the mold collar.

5. *Gas burners* should be handled with care to avoid denting or breaking the container or damaging the valves. Follow OSHA Regulations when operating, handling or transporting LP tanks and NEVER transport a gas burner while it is attached to the LP tank.

Checking Accuracy of Equipment

1. *Volumeter* - Accuracy may be checked by measuring the volume of a 1/30 cubic feet mold. The first reading should be taken on a flat surface and the second reading over the mold. This procedure should be performed three times and the measurements averaged to obtain the volume check (0.0333 $\pm$ .003 cu. ft.).

2. *Scales* - Accuracy of scales may be checked by weighing objects of known weight. This may be done by weighing various combinations of the weights that are included with the scales. (Example: 1,000 gram weights vs. 1,000 grams weight, 2,000 gram weights vs. 2-1,000 gram weights). The balance should be at a near-level position when in use.

3. *Rammer* - The rammer used in performing Test Method AASHTO T-99 should weigh 5.5 pounds (2,495 grams +/- 9 grams) and have a free fall of 12 inches (+/- 1/16 of an inch). The weight of the rammer may be checked by removing it from the sleeve and placing on a scale. The fall may be checked by placing the rammer at its maximum height in the sleeve and measuring the interior distance between the bottom of the rammer and the end of the sleeve.

SECTION 11 - DOCUMENTATION INSTRUCTIONS AT PROJECT LEVEL

The standard report form entitled, “Field and AASHTO Density Determinations” (M&T Form 504), shall be used to record all density determinations. At the time the density test is performed, the Technician shall fill out an original and one other copy. One copy shall be forwarded to the Division Engineer and one copy shall be retained by the Resident Engineer. These reports are not to be copied prior to transmitting, but the reports are to be submitted as they are prepared in the field. Provided the test data/results are entered into HiCAMS, copies of the density test reports are not to be sent to Materials and Tests. However, the reports will be sent to Materials and Tests for reviewing if requested by a Materials and Tests representative.

Each report is to be numbered consecutively according to the type of material being tested. When a check test is necessary, it shall carry the number of the original test that failed, plus an alphabetical designation. An example of this system of numbering would be: First embankment density test would be No. 1. All subsequent embankment density tests would carry consecutively higher numbers (i.e. 2, 3, 4, 5, etc). If embankment density test No. 32 failed, and a check test was completed, the check test would be numbered 32A. If on the same project, the Contractor begins constructing the subgrade, the first density test performed on the subgrade would be number 1.

All reports, including those showing densities below those required by the Specifications, are to be submitted. When a density test is completed, and it fails to meet the minimum requirements of the Specifications, there are two approaches that can be taken:

1. The Contractor is required to perform corrective action and then a check test is performed within five feet of the original test. In this case the corrective action taken by the Contractor will be described on the bottom of the test report made for the check test.
2. The Resident Engineer may consider the area in question as being acceptable without any additional work being required of the Contractor to bring the density to values required by the Specifications. In this situation the Resident Engineer will apply Section 105-3 of the Specifications and place a statement at the bottom of the report describing why he/she considers the results as being acceptable. Once the comment is added, the Resident Engineer shall sign the test report.

There is sufficient information provided on the report form to plot the locations of the density tests. This may be desirable on larger, more complex projects, but is not required. However, the Resident Engineer shall ensure that the minimum testing frequency as stated in the “Minimum Sampling Guide” or listed in this manual (refer to Section 2) is obtained.

In addition to the required information shown on the report form, the Technician shall note on the report those densities that are performed on pipe backfill and structure backfill. A sufficient number of these tests shall be performed to ensure that a Contractor’s backfilling operations are acceptable.

If, while performing a density test, the Technician encounters enough rock to prevent the completion of either Test 1, 1-A, or 2, then he/she shall fill out the report (M&T Form 504) by placing as much information as possible. The Technician should also note on the bottom of the report that the density test(s) could not be run due to rock. This report would then be handled in the same manner as all other reports.

Upon completion of each density report, a summary of the results should be entered into the Project Density Diary. An example of a typical diary is provided in Table 4 below. The Diary serves as a quick reference guide for all density tests performed on a project and can be utilized to ensure enough tests are being performed, the number sequences are correct and if enough “long tests” with curves are being performed. Each type of material requiring a density test should be listed in a separate section. For example separate sections would be created for a project with density test(s) in each of the following material classifications: Embankment, Subgrade, Lime Stabilized Subgrade, Cement Stabilized Subgrade, etc. These sections will be prepared in the following manner:

Contract Number: ___________________
Project Number: ____________________
Type of Material: ___________________
County: ____________________________

Test No.	Date Run	Sta.	Lane	Dist. from Center . . . Right or Left	Elev. Below Subgrade or Layer	Density Obtained	Remarks

Table 4

Density tests that are run on backfill material for pipes and structures shall be so noted under the remarks column.

<u>HICAMS Data Entry</u>

All density tests performed must be entered into the HiCAMs database. Since this database is utilized for project certification, results must be entered correctly to ensure accuracy when completing the final certification. Procedures for data entry into this system are beyond the scope of this manual. For assistance, consult the person in your office who has been trained in HICAMS.

SECTION 12 - INSTRUCTIONS FOR INDEPENDENT ASSURANCE

Since all Independent Assurance (I.A.) density tests are comparative tests, it is imperative that I.A. density tests be performed as accurately as possible. Tests shall be performed in accordance with the procedures outlined in the test method applicable to the material. If there should be a deviation from the prescribed procedures, the results will not be accepted.

Confidence limits were established for each comparative test. If the difference is outside the confidence limits, it will be considered as a poor correlation and an investigation will be required in order to determine the reason(s) for the discrepancy. In addition, the following instructions shall apply to all I.A. density tests.

1. The I.A. Technician shall locate the project Technician performing acceptance density tests and determine if the individual has completed the required acceptance test on the current lot of material.

2. If the Technician has completed the acceptance test(s) and the hole is not covered, the I.A. Technician shall perform a comparative test next to the project acceptance test. The I.A. Technician shall obtain the acceptance test results.

3. If the Technician has completed the acceptance tests and the hole is covered with another lift, the I.A. Technician shall request the Technician to perform another acceptance test within five feet of where the I.A. Technician performs a comparative density test.

4. Once the I.A. Technician has completed the test and has obtained results from the Technician's acceptance test, he/she shall fill out the correlation sheet as explained below:

    A. When designating type of material the I.A. Technician shall use ABC, CTBC, Subgrade, Lime Stabilized Subgrade, Cement Stabilized Subgrade, Aggregate Stabilized Subgrade, or Embankment.

    B. For Conventional Density tests 1-A, the I.A. Technician shall record the percent compaction only; put a dash in all other spaces. For ABC, the I.A. Technician shall record the in-place Dry Density (lbs. / $ft.^3$) and percent compaction. For all other Conventional Density Tests, the I.A. Technician shall record all the required information.

5. At least 90 percent of all I.A. density tests shall be performed within five feet of a project acceptance test and at least 25 percent of these tests will include Tests 1 with a moisture-density curve. The project personnel shall perform Test 1 when the I.A. Technician performs a Test 1.

6. Each moisture-density curve made shall be plotted on the chart provided for this purpose and turned in as part of the I.A. density report. A sample of soil from the same soil that was used to run a curve shall be sent to the Materials and Tests Central Laboratory for the purpose of having the Soils Laboratory perform a moisture-density curve. The moisture-density curve plotted the Soils Laboratory will be compared to the moisture-density curve plotted by the I.A. Technician. If the moisture-density curves are not in reasonable agreement, steps shall be taken immediately to determine the cause of the discrepancy and make the necessary corrections to promote better agreement.

7. On each visit to a project, the I.A. Technician shall complete a project report M&T Form 901, showing tests made and samples taken. This report shall be signed by the Technician or the Resident Engineer and the I.A. Technician, and a copy shall be left with the Technician or Resident Engineer for inclusion in the project files.

Test Results Evaluation Procedure

Once the test results and other pertinent information have been recorded on the correlation sheets, the difference between I.A. and acceptance test results will be computed by subtracting one from the other. The next step consists of looking in the Confidence Limits Table for the particular material being evaluated and comparing the difference with the established limits. The difference is then rated as Excellent, Good or Fair. If the difference is outside the confidence limits, it will be considered as a Poor Correlation and unless the reasons are already known, an investigation will be required in order to determine the reasons for the discrepancy.

Confidence Limits Table: Aggregate Base Course

Properties	Sign	Excellent Maximum Limit	Good Maximum Limit	Fair Maximum Limit
% - Compaction	+/-	2.4	3.1	3.9

Table 5

Confidence Limits Table: Subgrade and Embankment

Properties	Sign	Excellent Maximum Limit	Good Maximum Limit	Fair Maximum Limit
In-Place dry density (PCF)	+/-	3.2	4.1	5.0
Estimated Optimum Moisture Content (%)	+/-	1.6	2.1	2.5
AASHTO T-99 dry density (PCF)	+/-	1.9	2.4	2.9
Percent Compaction	+/-	2.4	3.1	3.8

Table 6

SECTION 13 - RESPONSIBILITIES OF PROJECT PERSONNEL IN CONJUNCTION WITH INDEPENDENT ASSURANCE PERSONNEL

I.A. Technicians are representatives of the Materials and Tests Unit (funded by the FHWA) whose duties and responsibilities are to take comparative samples of and perform comparative tests with project personnel on Federally Funded Projects. Each time an I.A. Technician visits a Federal Aid project, they are required to fill out a report (M & T Form 901) and leave a copy with project personnel. There is a place on the report for either the Resident Engineer or the Technician to sign. The signature of the project representative signifies that the project personnel know an I.A. sample has been taken, and the project personnel as an individual, accepts the results of the test as being reasonable.

Project personnel must furnish whatever information is necessary to the I.A. Technician. For density testing this information would include: (1) Location and results of project acceptance tests, (2) if a moisture-density curve was used for the determination of optimum moisture, the I.A. Technician should be advised of this and also of the value used, (3) any other information, such as changes that would affect the results of the tests. This does not mean that project personnel are to direct the I.A. Technician as to where the samples and/or tests are to be performed. This determination is the responsibility of the I.A. Technician.

Upon receipt of a copy of an I.A. Technician test report, project personnel should attach it to the related project acceptance test and place both tests in the project files. It is the responsibility of the Resident Engineer to furnish this information to the I.A. representative.

SECTION 14 - CONCLUSION

There will be instances where difficulties will be encountered that the project personnel cannot solve. If this occurs, the Resident Engineer should contact the Soils Laboratory at (919) 329-4150 and request assistance. If, in the event the results obtained by the I.A. Technician and project acceptance samples/tests are not in reasonably close agreement, the two groups of individuals performing the testing must meet and try to determine why the difference exists. If they are unable to arrive at a solution, the Soils Laboratory shall be notified, and whatever steps are necessary to arrive at a solution will be taken. Below is a chart that provides the general ranges of optimum moisture and maximum dry density for the major soil types. This chart is general and there may be individual soils that, while having the same general characteristics, may fall outside the values given in the chart. This chart is furnished for information purposes only and is not to be used in any other manner.

AASHTO Classification	Visual Description	Maximum Dry Weight (lb/ft^3)	OMC Range
A-1	Granular Materials	115-142	7-15
A-2	Granular Materials/Soils	110-135	9-18
A-3	Fine Sand and Sand	110-115	9-15
A-4	Sandy Silts and Silts	95-130	10-20
A-5	Elastic Silty Clay	85-100	20-35
A-6	Silt-Clay	95-120	10-30
A-7-5	Elastic Silty Clay	85-100	20-35
A-7-6	Clay	90-115	15-30

Table 7